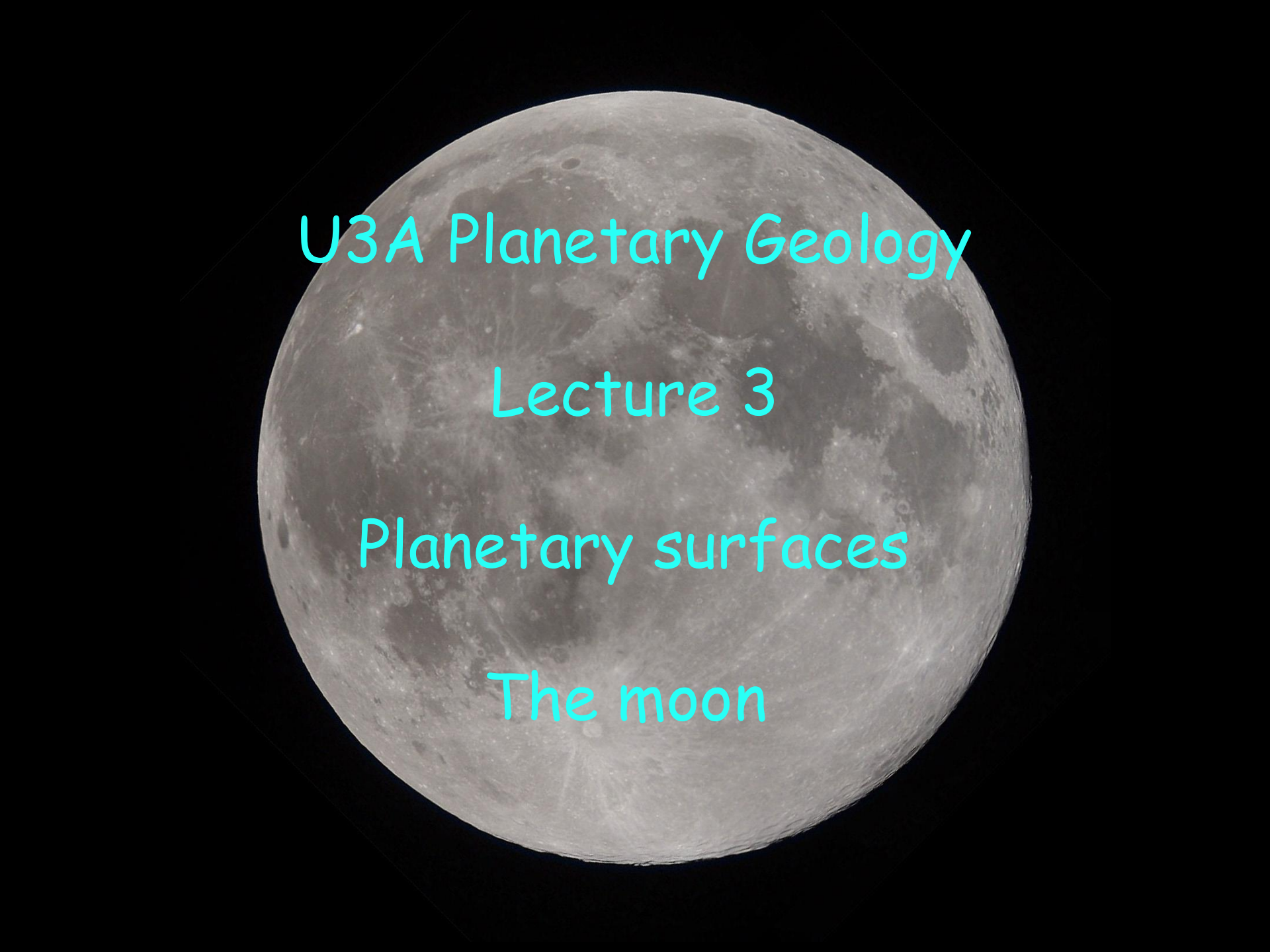
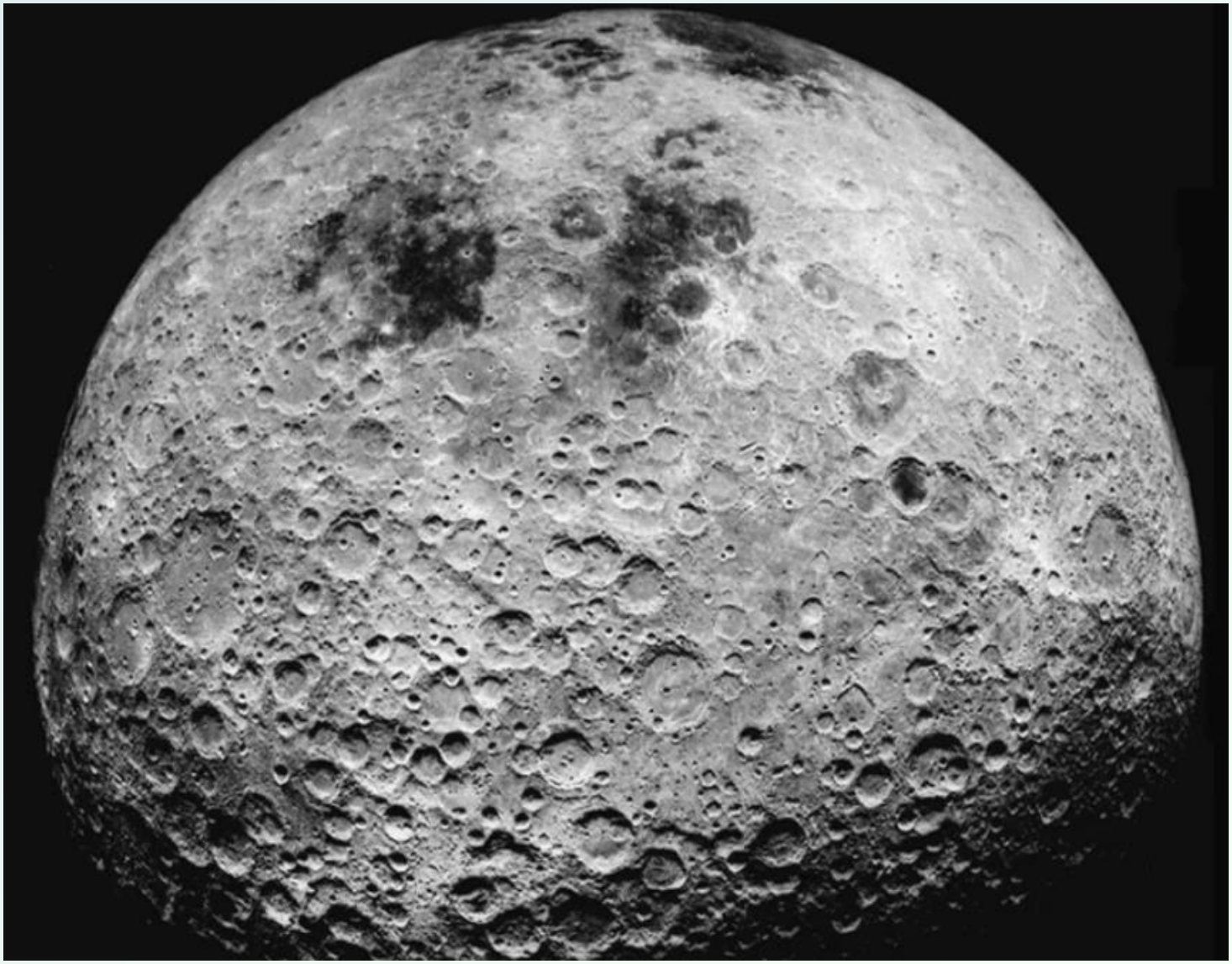
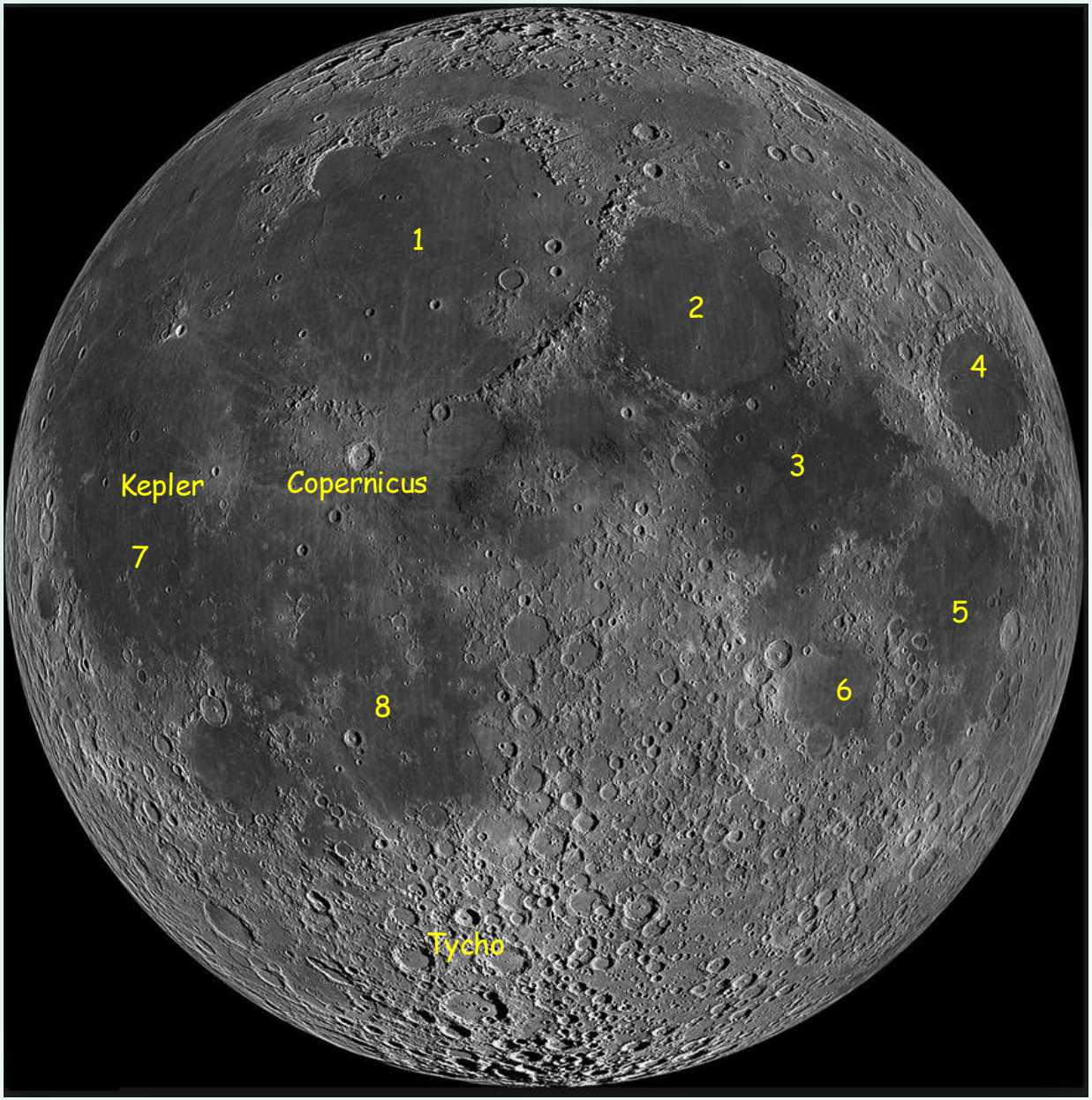

U3A Planetary Geology
Lecture 3
Planetary surfaces
The moon

Far side of the Moon



Nearside of the Moon

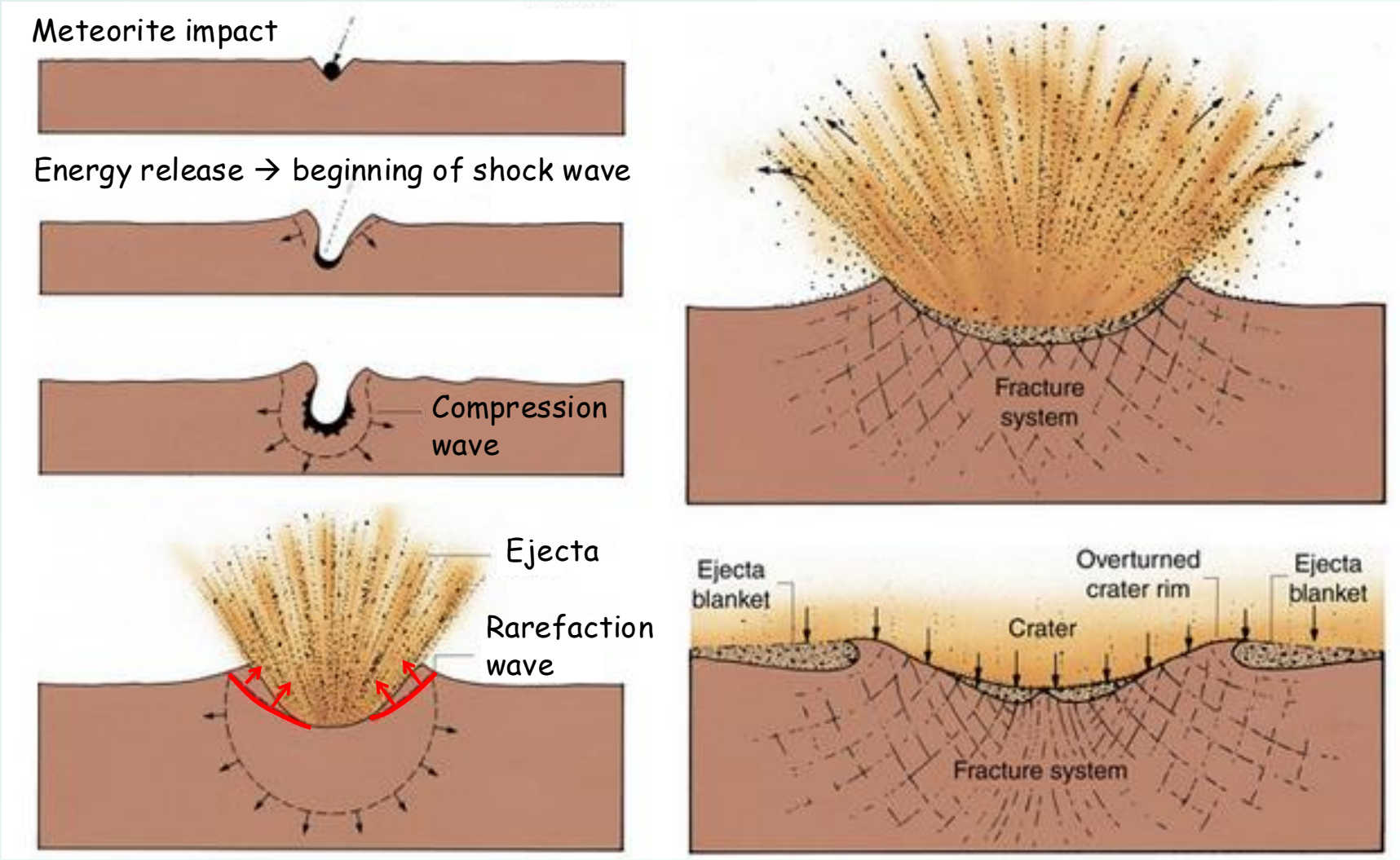


1. Mare Imbrium
2. Mare Serenitatis
3. Mare Tranqillitatis
4. Mare Crisium
5. Mare Fecunditatis
6. Mare Nectaris
7. Oceanus Procellarum
8. Mare Humorum

Impact cratering

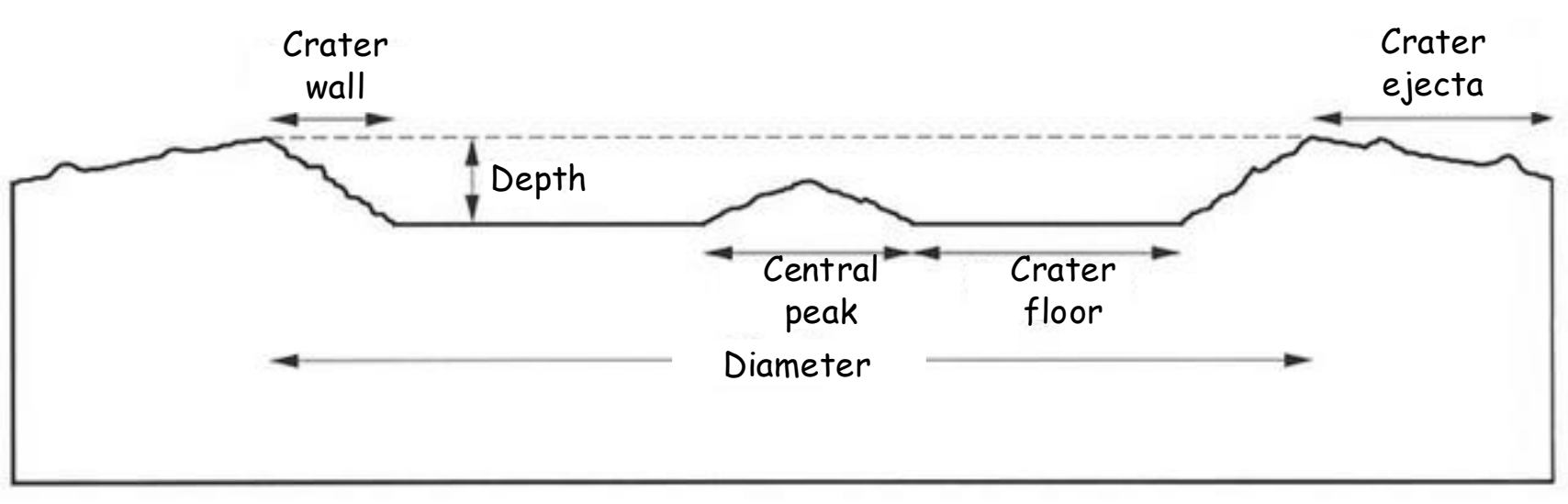
- Craters are very common features on the surfaces of planets and moons (abundant on our Moon)
- ~200 impact craters known on Earth
- produced by hypervelocity impacts* :
  - meteorites
  - asteroids
  - comets
- their origin was subject to much debate → late 19th century
- clearly different to volcanic craters (larger, circular outlines)
- hypervelocity impacts between 4 and 40km/sec
- enormous energy release (5-10m diameter meteorite equiv. ~10-15megatonnes TNT, Shoemaker-Levy ~6teratonnes TNT)

Meteorite impact time sequence



Meteorite crater X-section

- As rocks rebound elastically → often form a central peak
- edges of crater are uplifted and overturned →folded backwards and outwards

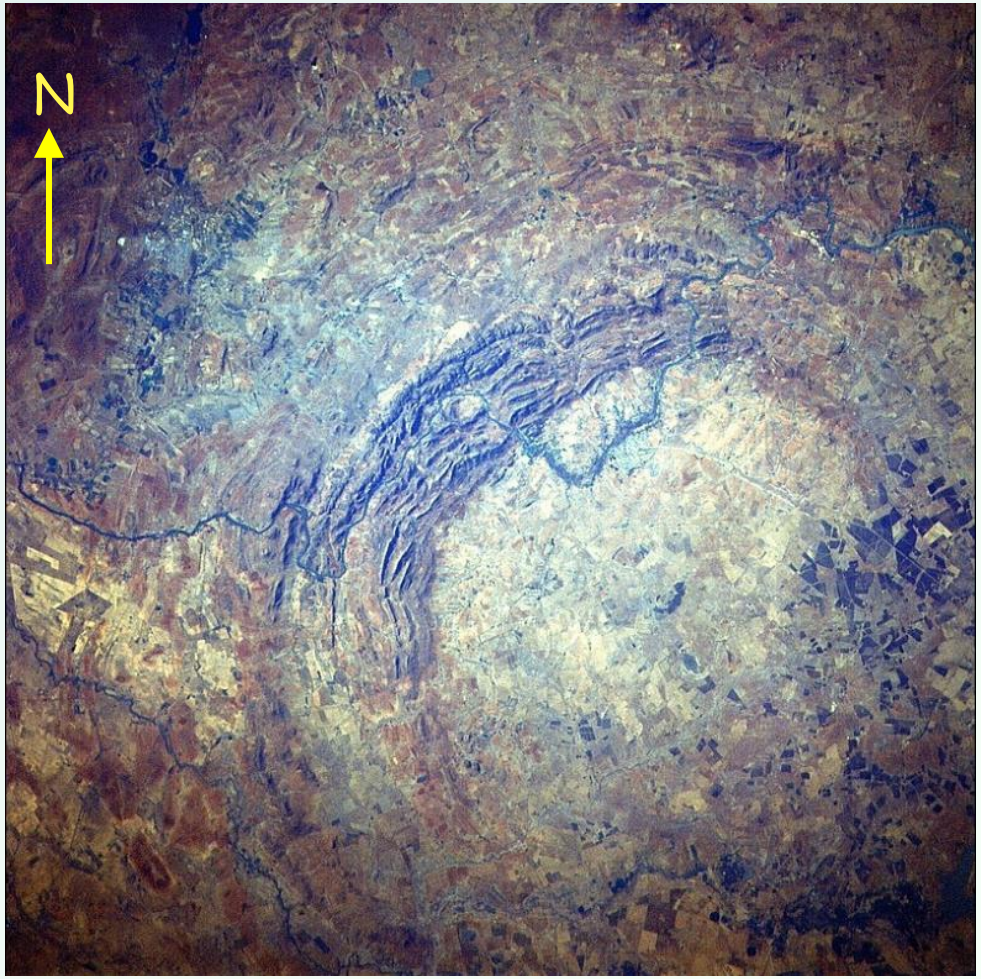


Barringer meteorite crater - Arizona, USA

- Formed ~50,000years by an asteroid 30-40m in diameter
- crater → 1200m diameter, 170m deep, rim rises 45m above plain
- surrounded by ejecta blanket of small hills

Vredefort crater, South Africa

- Largest verified crater on Earth (~300km diameter)
- ~2billion years old
- result of 20-25km asteroid impact



Satellite photograph,
Vredefort crater

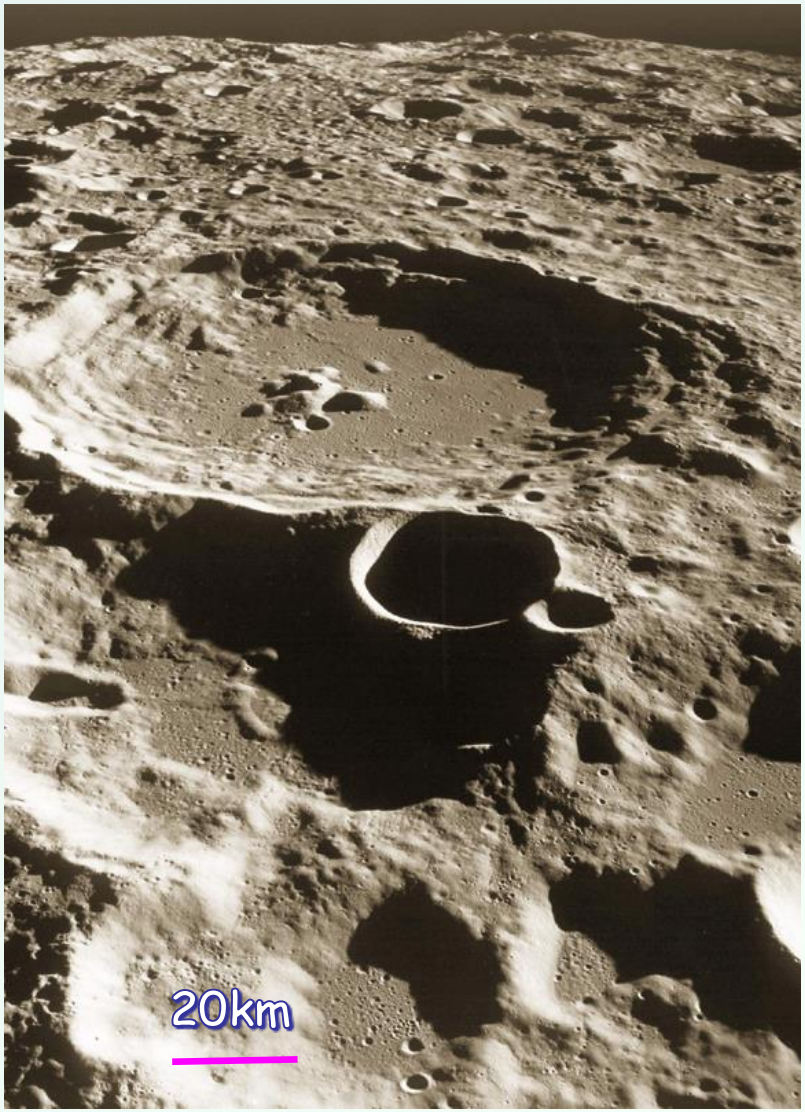
Wolfe Creek crater, WA

- Formed ~120,000 years ago
- ~875m in diameter, 60m deep
- prominent raised rim

Features of impact craters

Meteorite impacts form most if not all of the following features:

- Circular outline
- raised rim
- slump terraces
- central peak
- ejecta blanket
- secondary craters
- rays

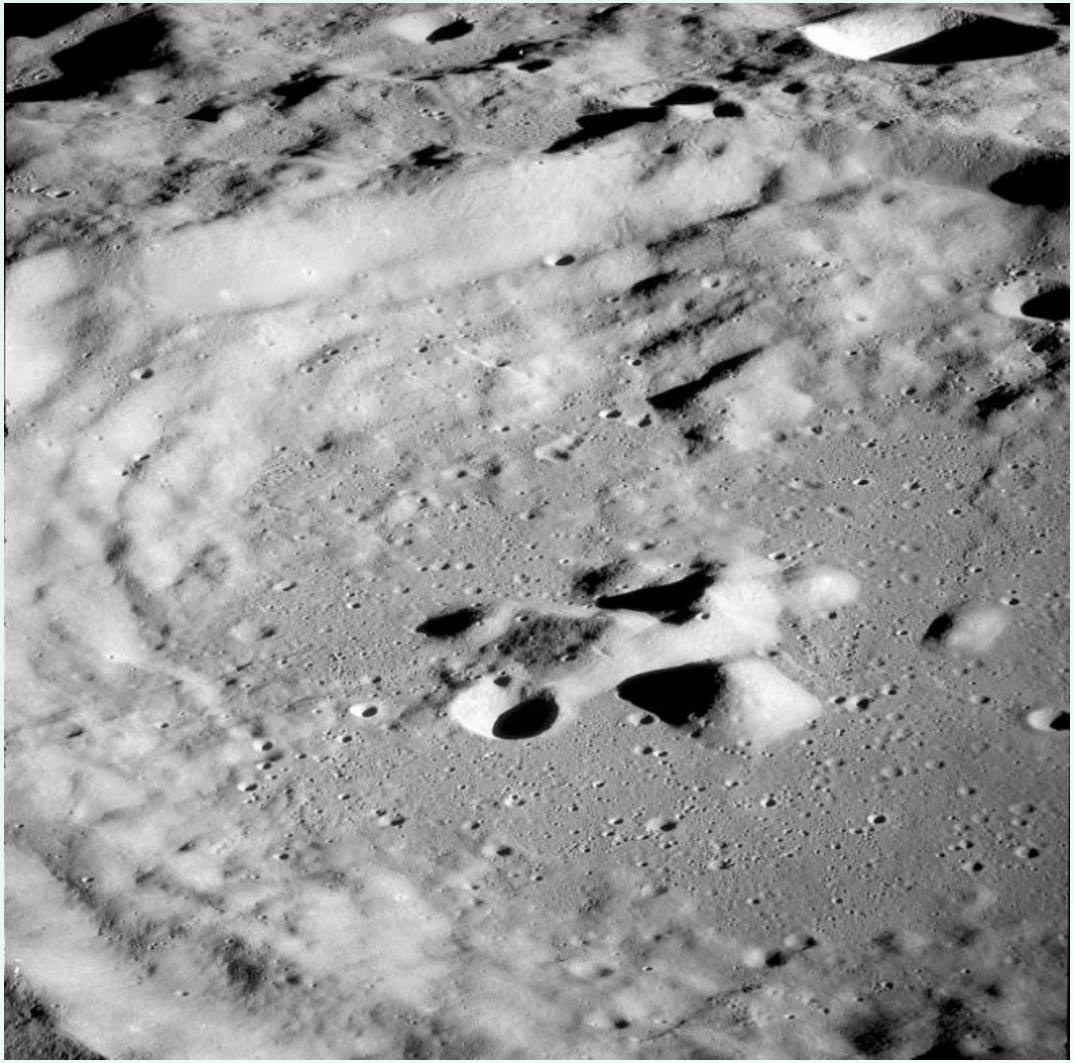


Daedalus crater,

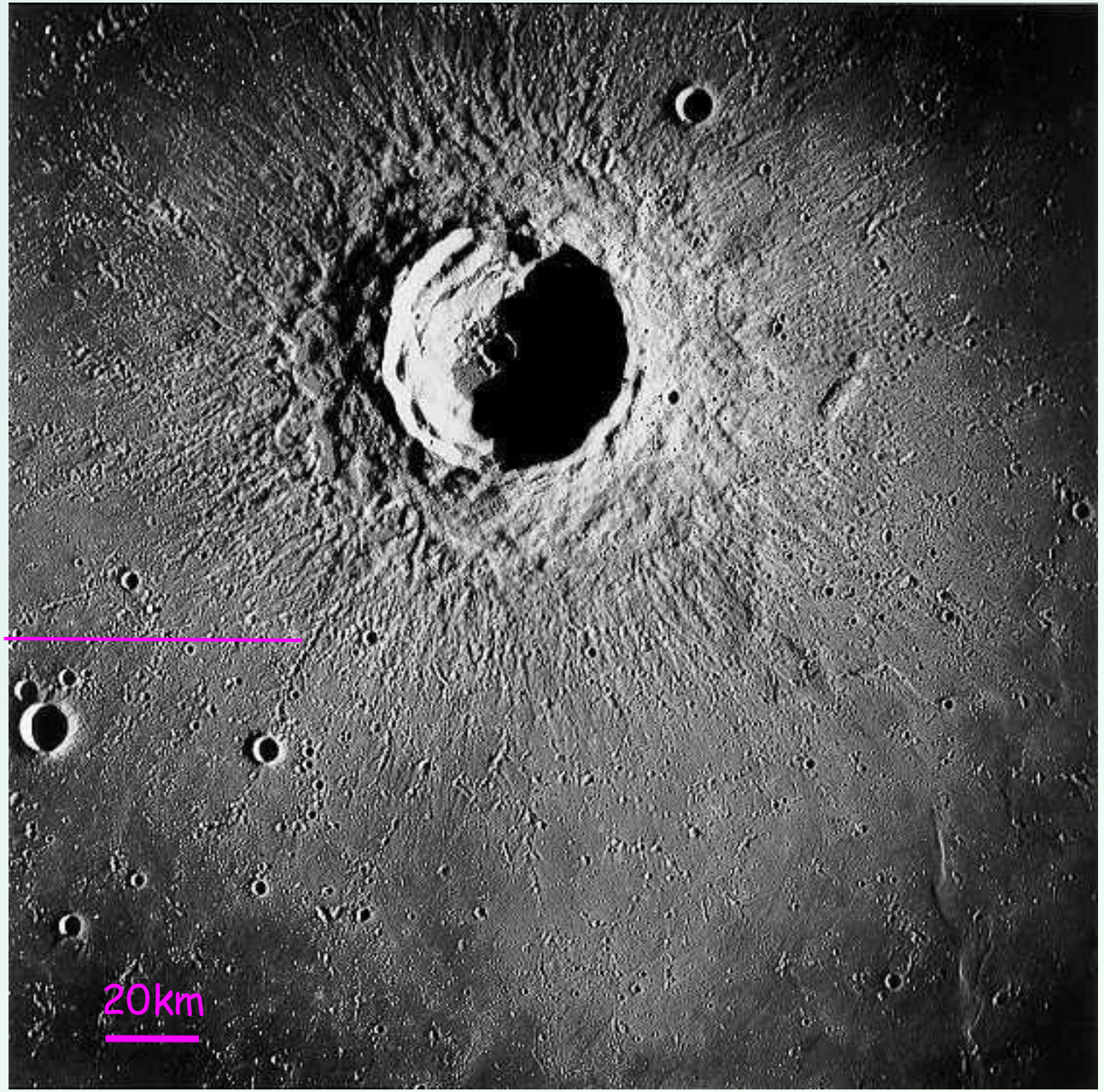
Far side of Moon

Closeup of interior of crater Daedalus

- Located on far side of the Moon
- crater wall is terraced, cluster of central peaks

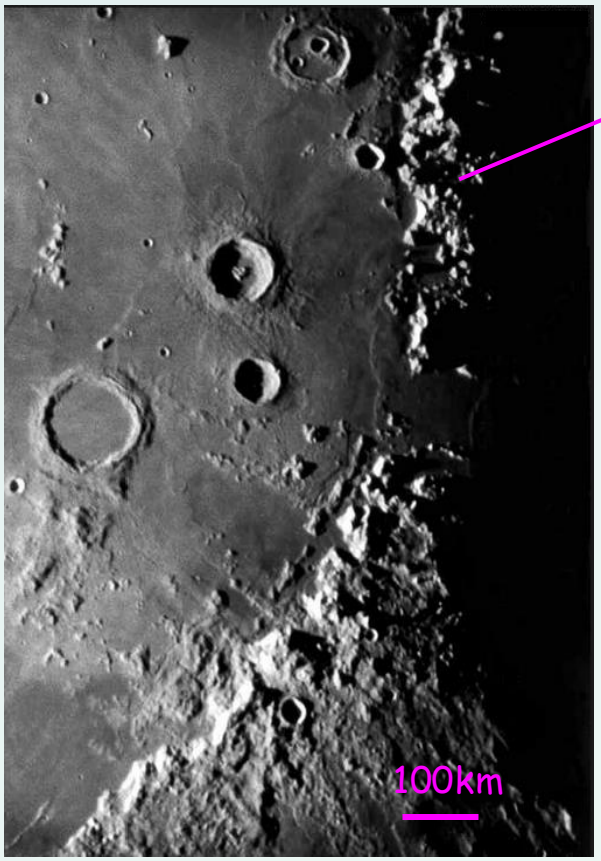


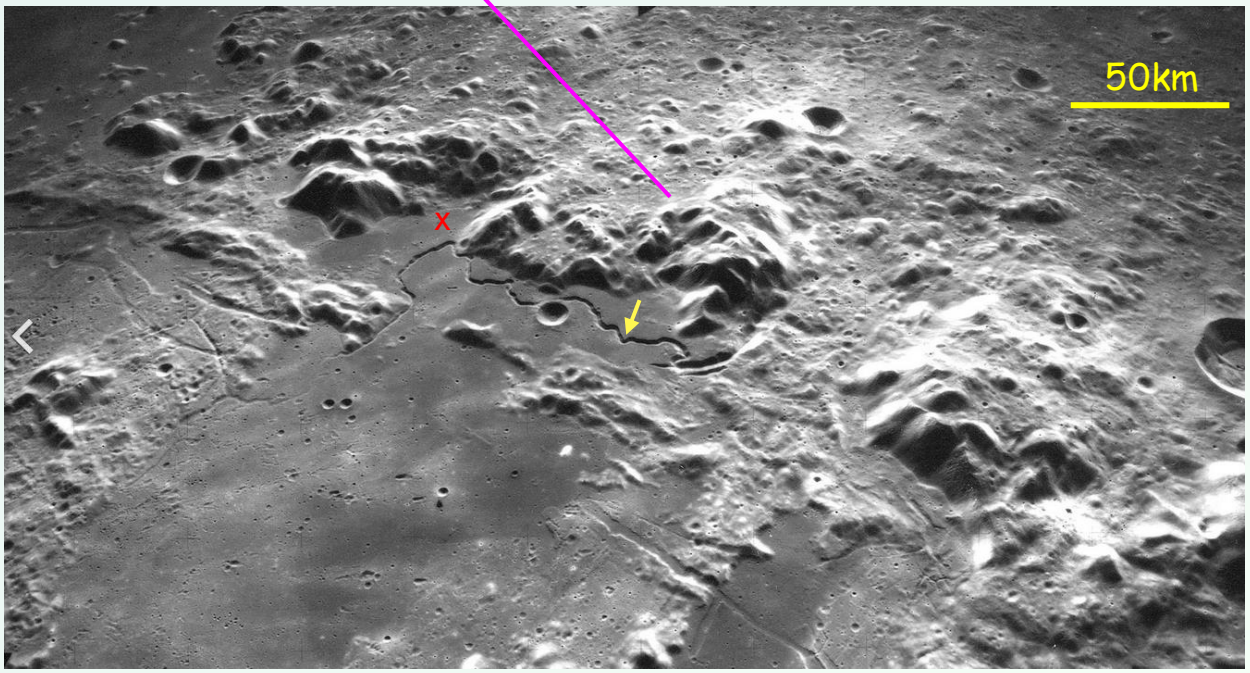
Characteristics of crater Timocharis



Impact craters – raised rim

- Apennine Mtns are an extreme example of an uplifted crater rim
- mountain range up to 5km high on SE edge of Mare Imbrium

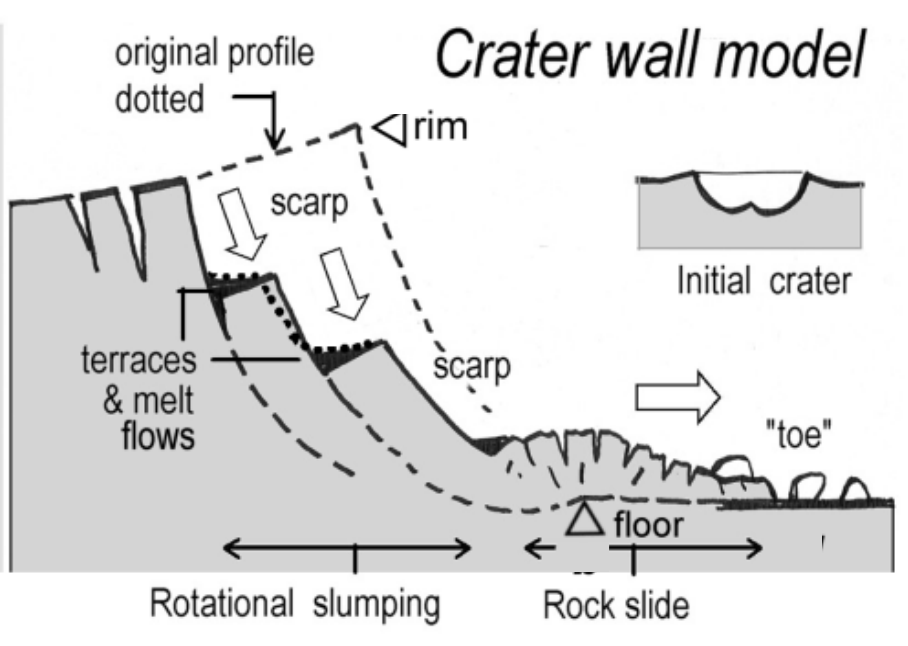


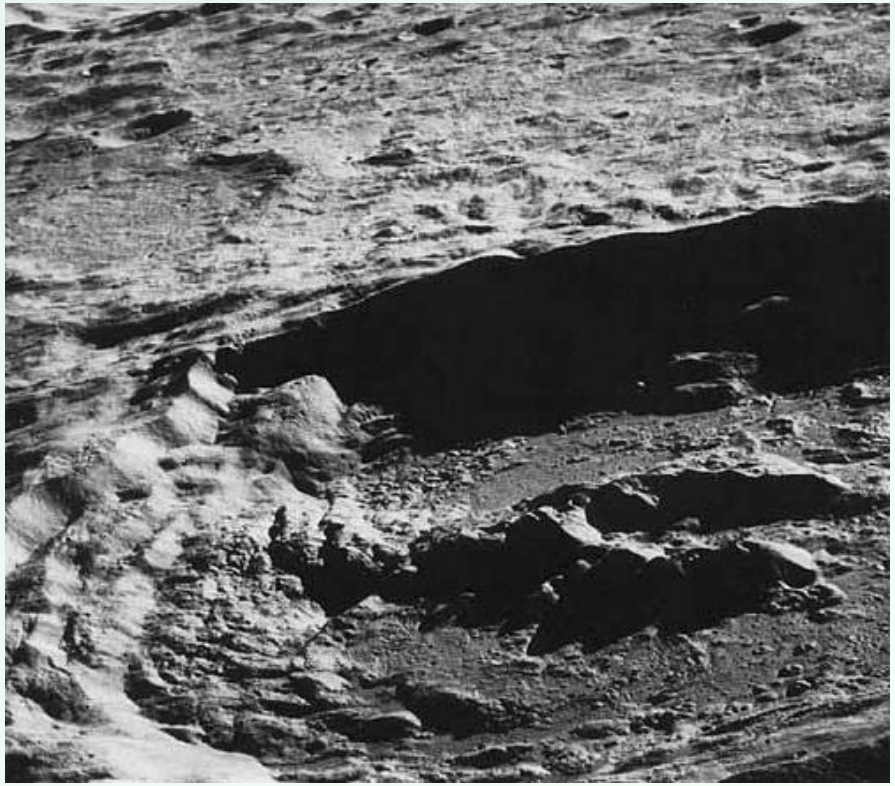


Oblique view of Apennine mountains

Impact craters – slump terraces

- Ring of steep terraces, distinctive feature of large impact craters
- after impact, material on inside of rim no longer supported on one side → failure of crater wall
- consolidated material collapses by rotation → terraces and scarps



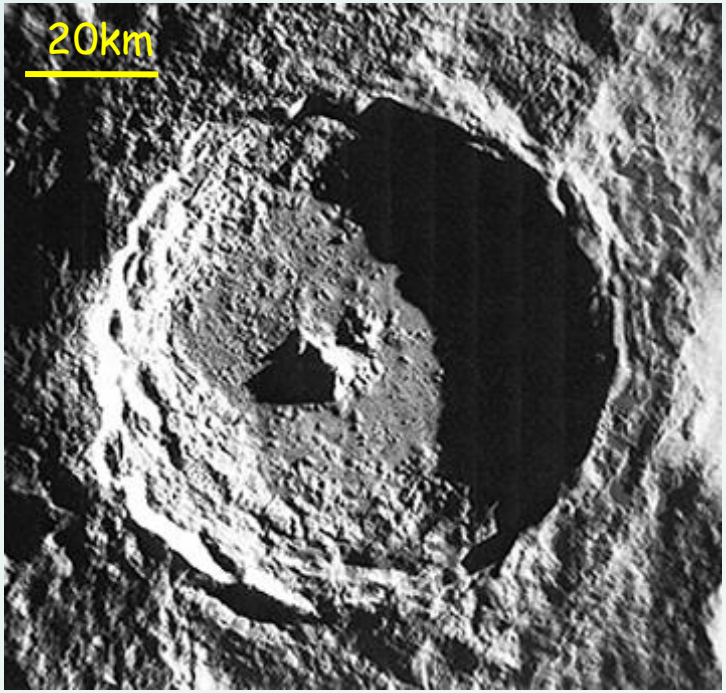


King crater on the Moon far side

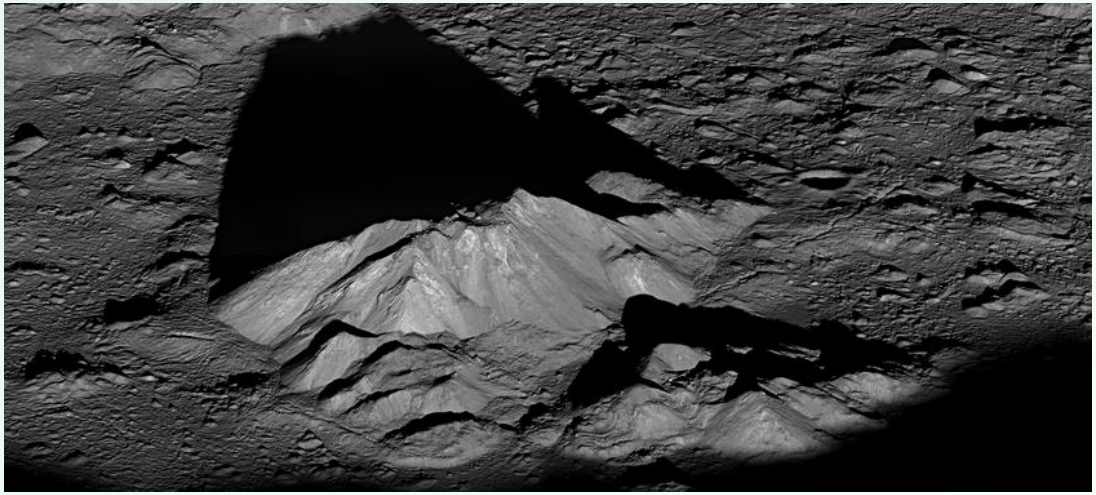
Impact craters – central peak

- Large craters (>4km diameter) tend to have central peaks
- peaks are local rocks tipped up on end
- formed by elastic rebound at moment of impact

Water droplet



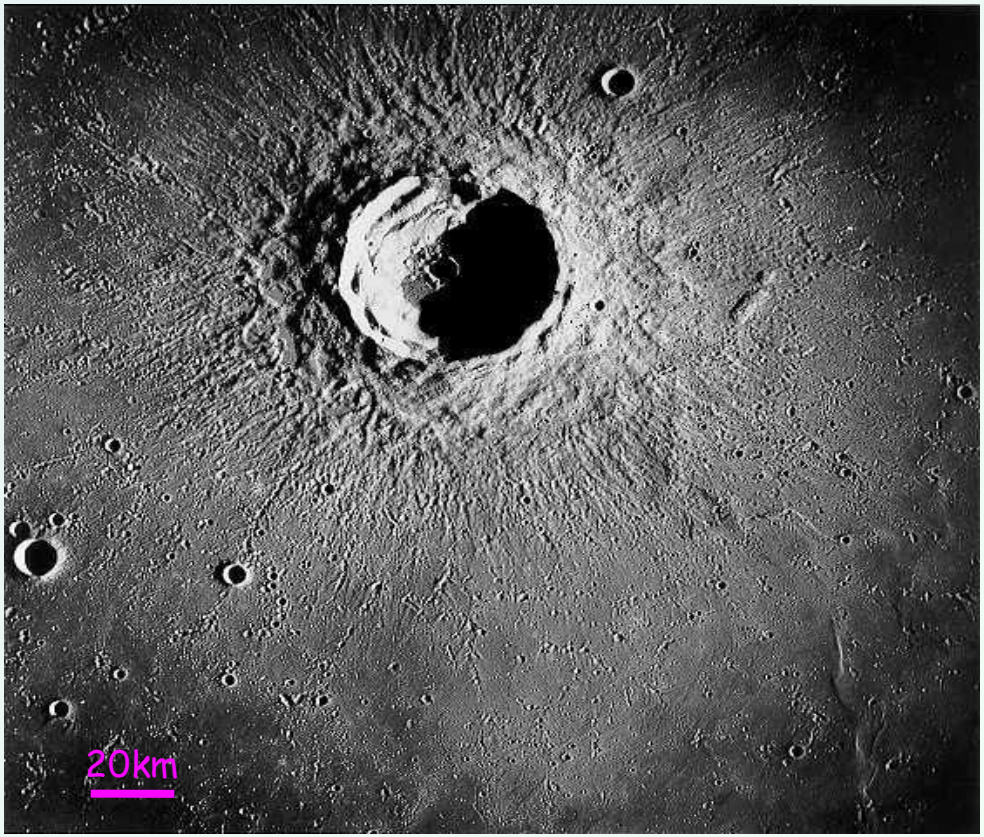
Central peak, Tycho crater



Central peak, Tycho crater
(lunar reconnaissance orbiter, 2011)

Impact craters – ejecta blankets

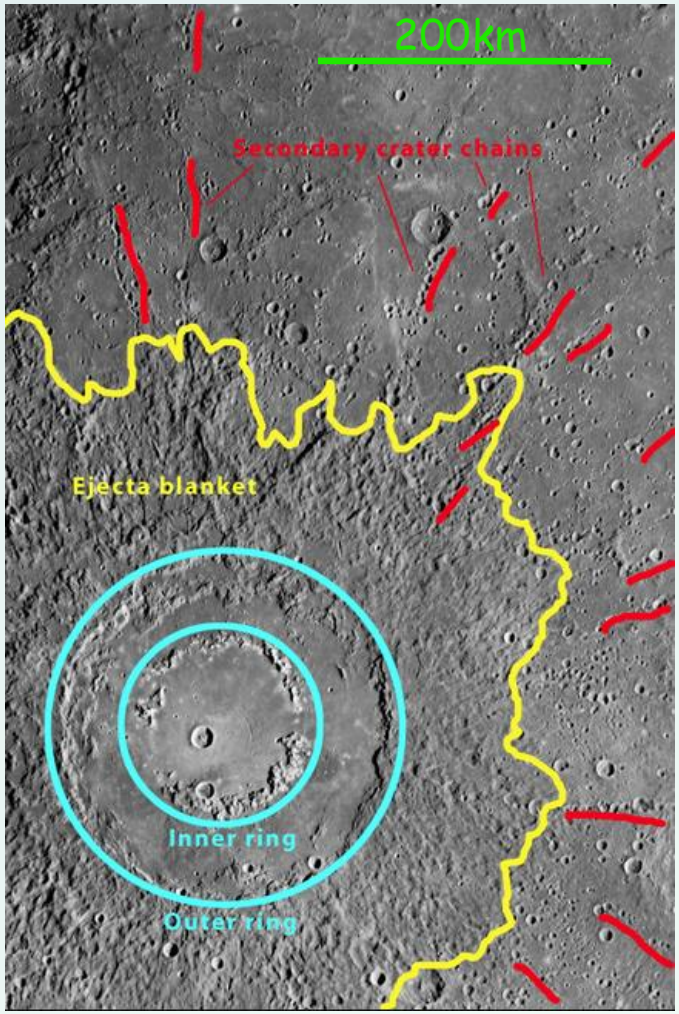
- Ejecta blanket – material blasted from crater by impact
- ejecta blankets around younger lunar craters → well preserved
- over billions of years → ejecta blankets eroded by micro-meteorites → impact at full cosmic velocities



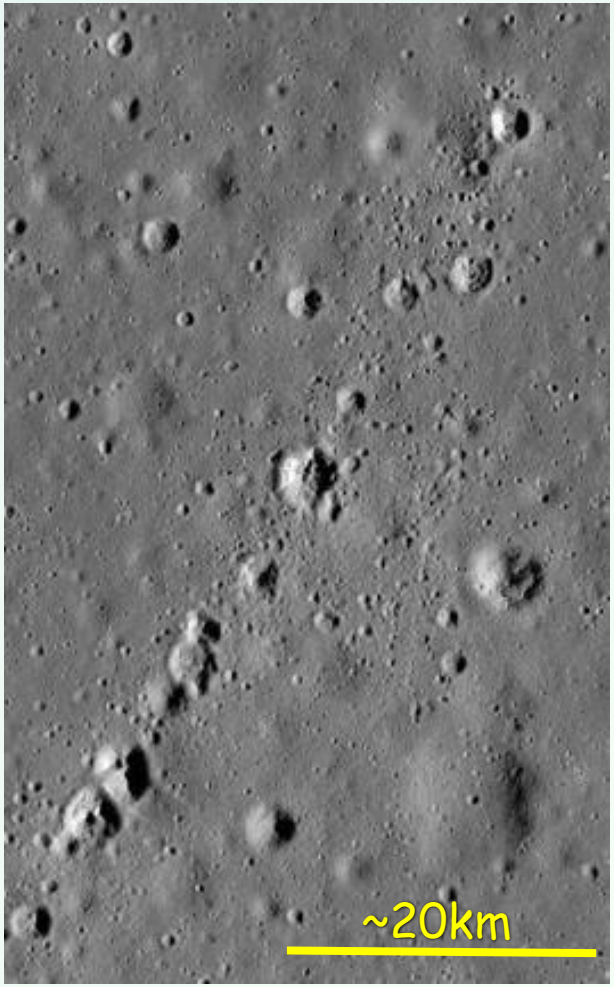
Ejecta blanket around Timocharis crater

Impact craters – secondary craters

- Secondary crater – impact crater formed by ejecta from larger crater sometimes form radial crater chains



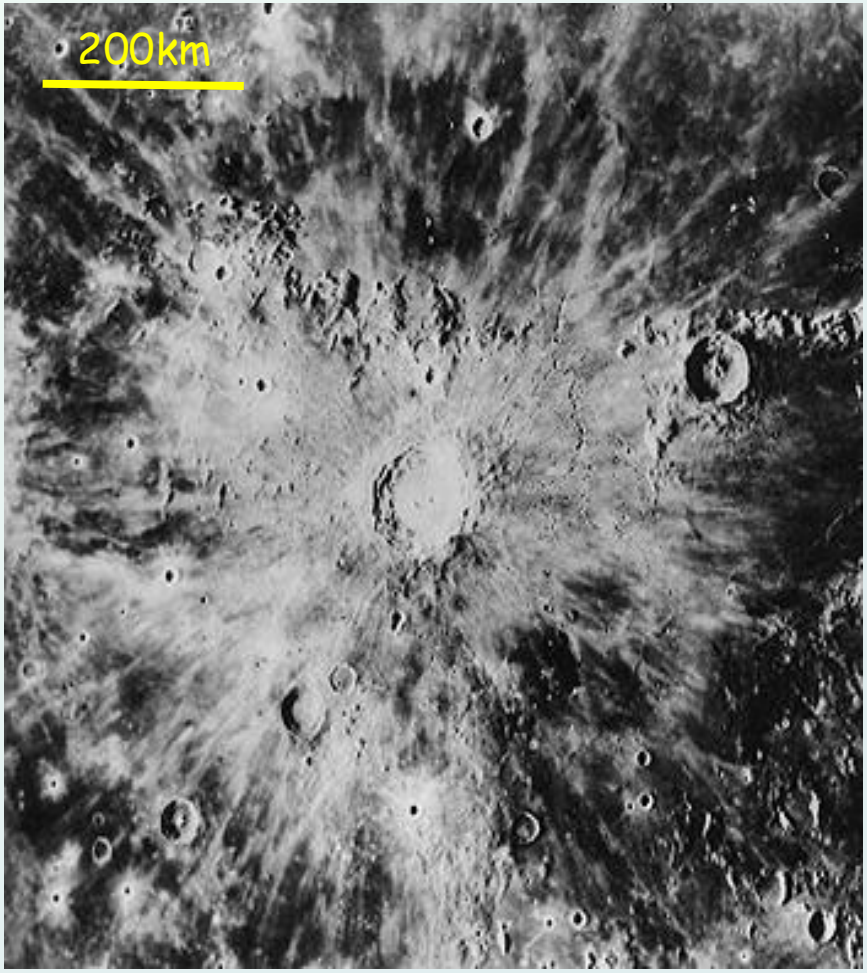
Double ring basin, Mercury



Radial secondary craters

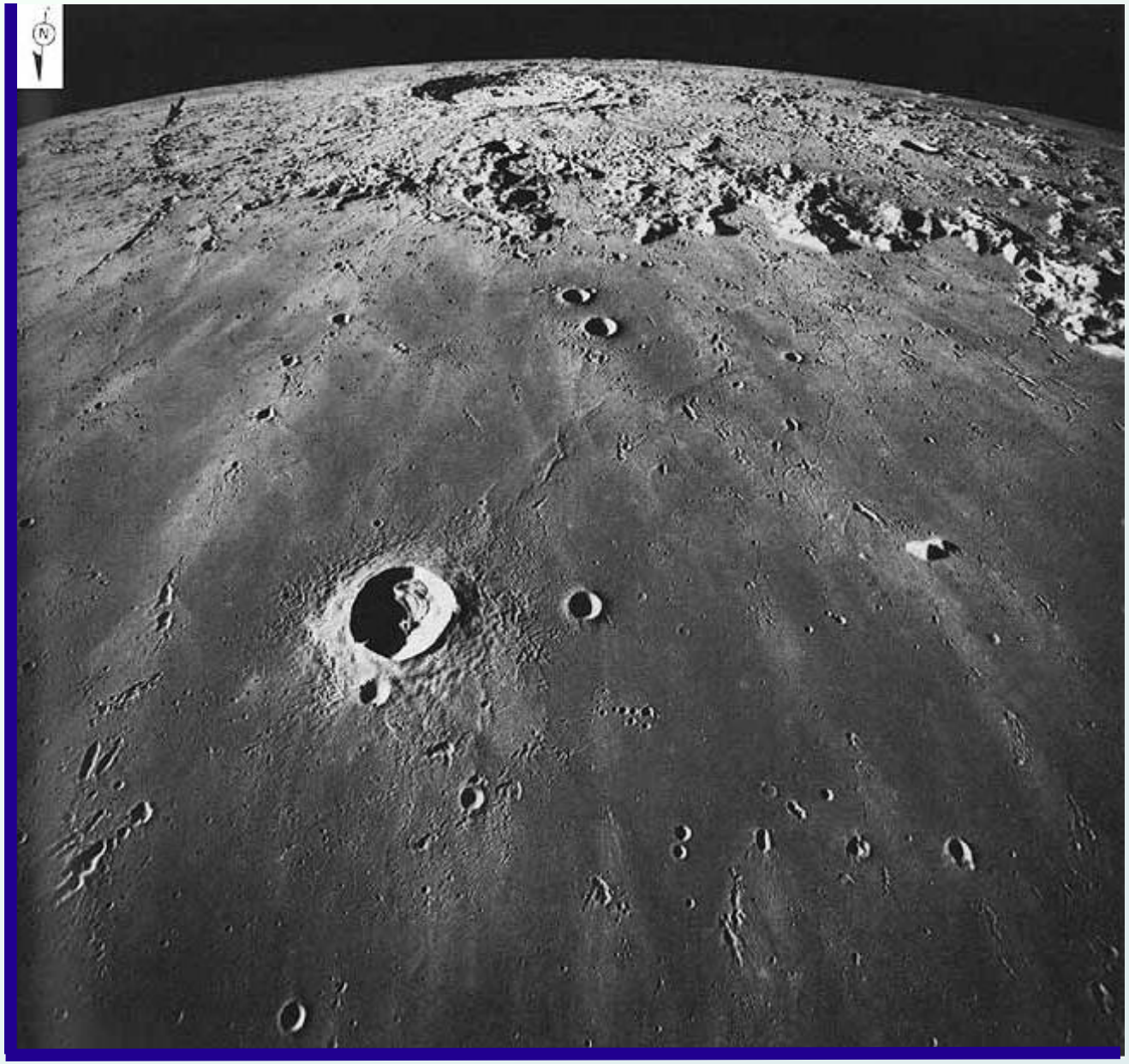
Impact craters – rays

- Rays – bright radial streaks of fine ejecta from meteorite impact
- follow simple trajectories → can extend for large distances
- ray craters youngest craters on the Moon (e.g. Tycho, Copernicus, Kepler)
- all these craters have bright ray systems around them
- rays are eventually reworked by micrometeorites



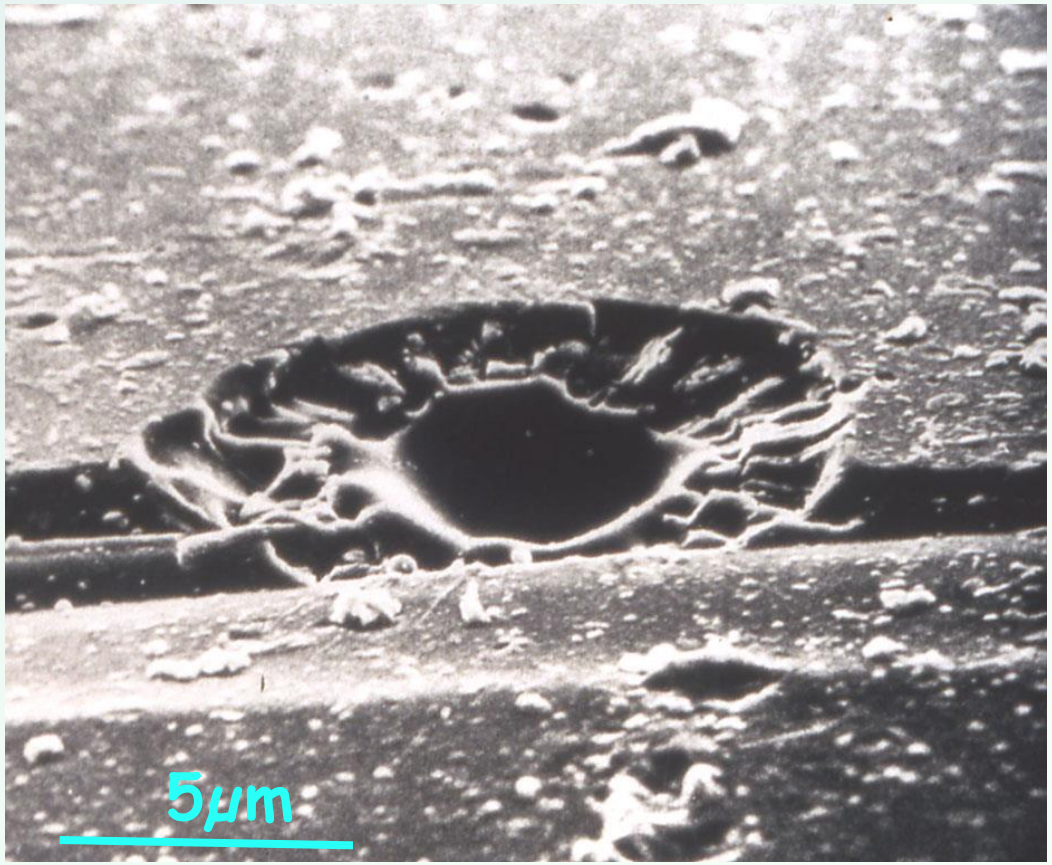
Crater Copernicus

Oblique view across Mare Imbrium to Copernicus



Zap pits

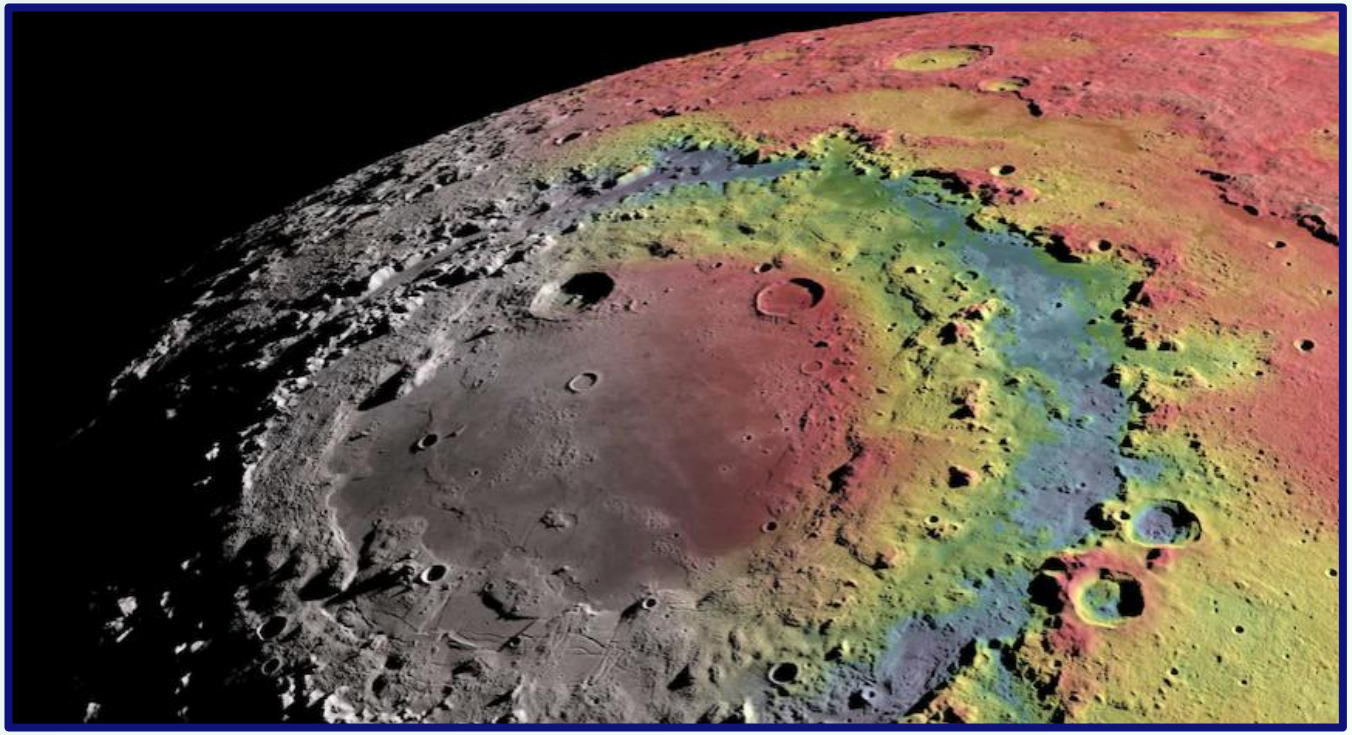
- Zap pits – tiny craters (~10μm across) found on surface of Moon rocks (only seen using scanning electron microscope)
- have fused glass linings where impacted material melted
- microscopic pieces of debris surround pits equivalent to ejecta



SEM image of a zap pit on surface of lunar rock

Large multi-ringed basins

- Multi-ringed basins – giant, complex, impact structures
- central uplift area expands → multiple rings of uplifted rocks
- forms gigantic rings, largest are 1500 – 2000km across
- larger impacts probably destroyed early protoplanets

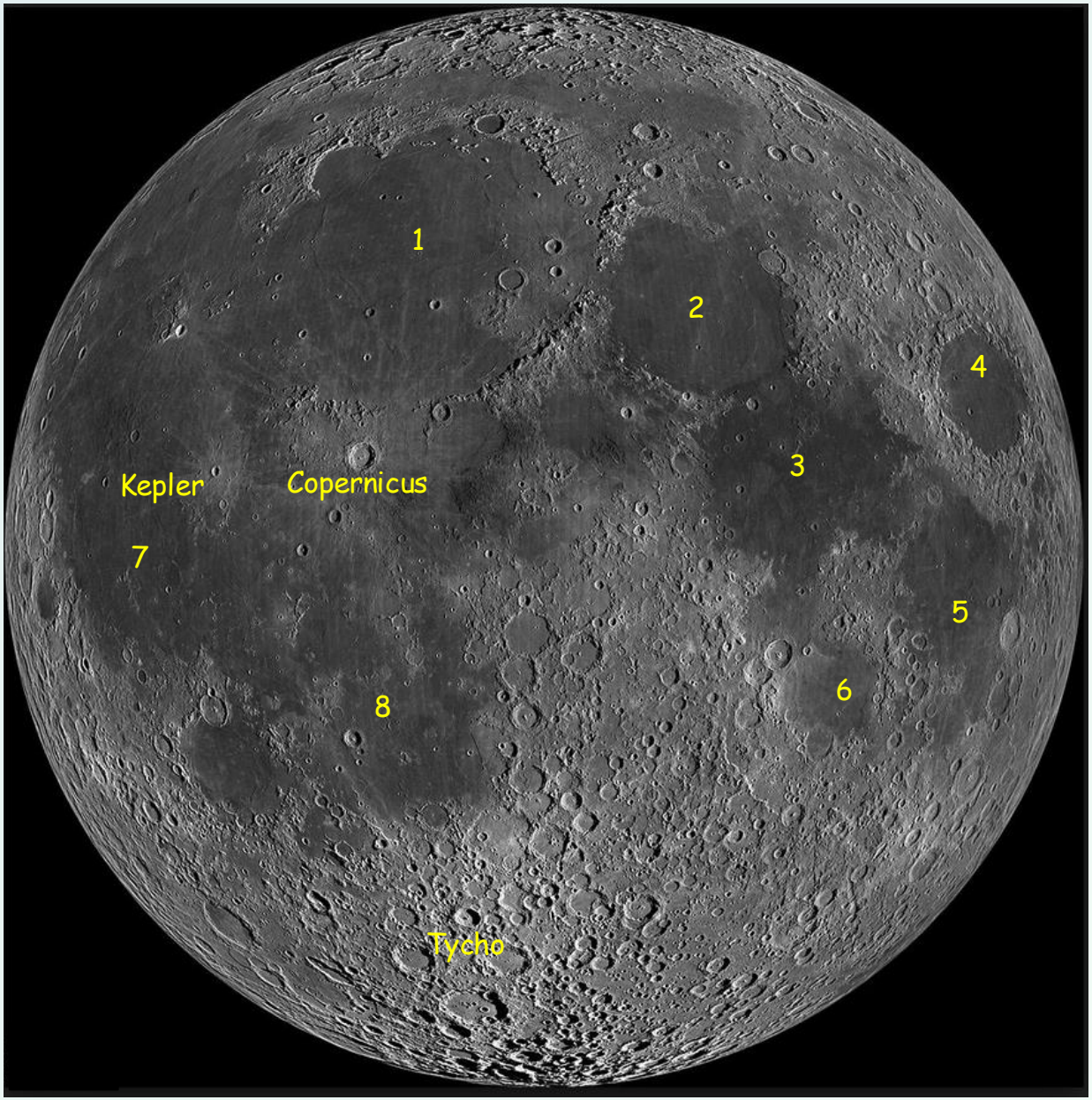


Orientale basin, moon
(930km diameter)

Nearside of Moon

- Pale coloured areas are massively cratered, dark coloured areas contain relatively few craters
- Gallileo described dark coloured areas as seas and gave them the name maria (singular = mare)
- these areas are flood basalts
- rocks collected from these areas are the driest rocks ever observed
- there are no hydroxyl minerals present unlike terrestrial basalts

Nearside of the Moon



1 Mare Imbrium

2 Mare Serenitatis

3 Mare Tranqillitatis

4 Mare Crisium

5 Mare Fecunditatis

6 Mare Nectaris

7 Oceanus Procellarum

8 Mare Humorum

The Moon

- Two-fold classification of the surface:
  - the lunar maria (mare = Latin for sea)
  - the lunar Highlands

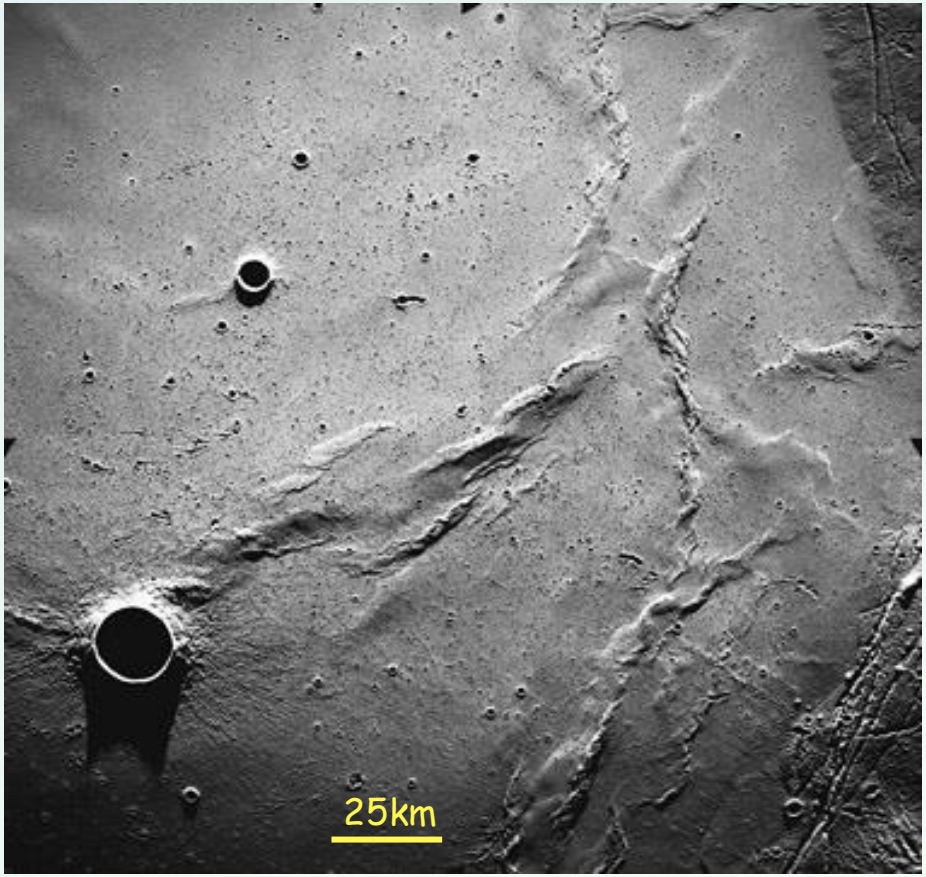
- the maria - dark coloured plains formed from flood basalt lava flows, relatively few craters

- the Highlands: pale coloured hilly areas of intense cratering and multi-ringed basins

- maria formed secondary crust on Moon when lava filled giant impact basins over period of several hundred million years

Lunar maria - lava flows, Sea of Serenity

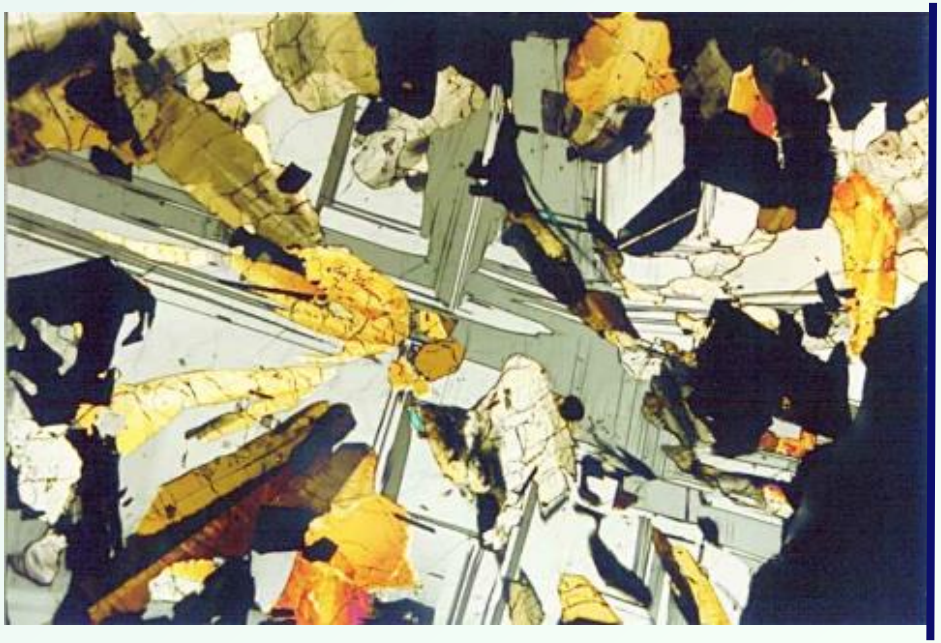
- Maria → dark coloured plain regions formed by flood basalts
- series of flow features with bulbous edges present on maria
- basalt lava poured on to surface → covered very large areas → younger than highlands



Lunar basalt

Lunar basalt from

Mare Serenitatis



Lunar basalt in

thin section (X polars)

Lunar basalt v terrestrial basalt

- Similar in appearance
- typical lunar basalt mineral assemblage:

clinopyroxene	~59%
plagioclase	~30%
ilmenite	~10%
olivine	~1%

- lunar basalts → devoid of hydrated minerals → driest rocks known
- lunar basalts → depleted in Na, K, Rb, Bi, Zn c.f. terrestrial basalts
- enriched in Ti, Ca, Fe and Cr c.f. terrestrial basalts

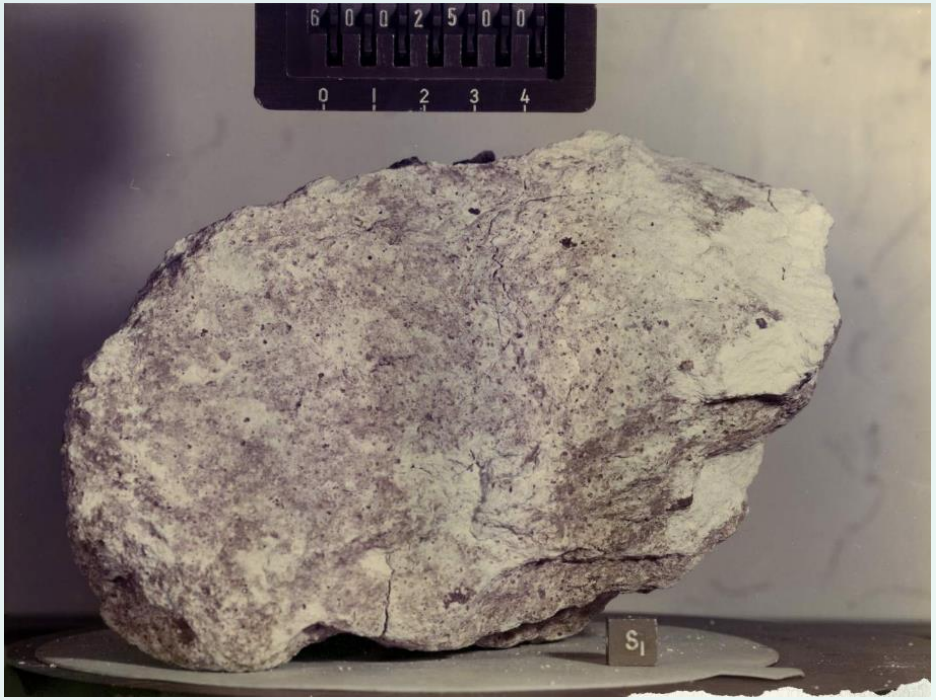
Lunar highlands

- Pale coloured regions on the Moon → lunar highlands
- mountainous areas covered by intense pattern of impact cratering
- contain numerous multi-ringed basins
- appear like rolling hills but can reach 10,000m in height
- light coloured rocks in highlands → anorthosites*
- majority of rocks in highlands are brecciated from impacts

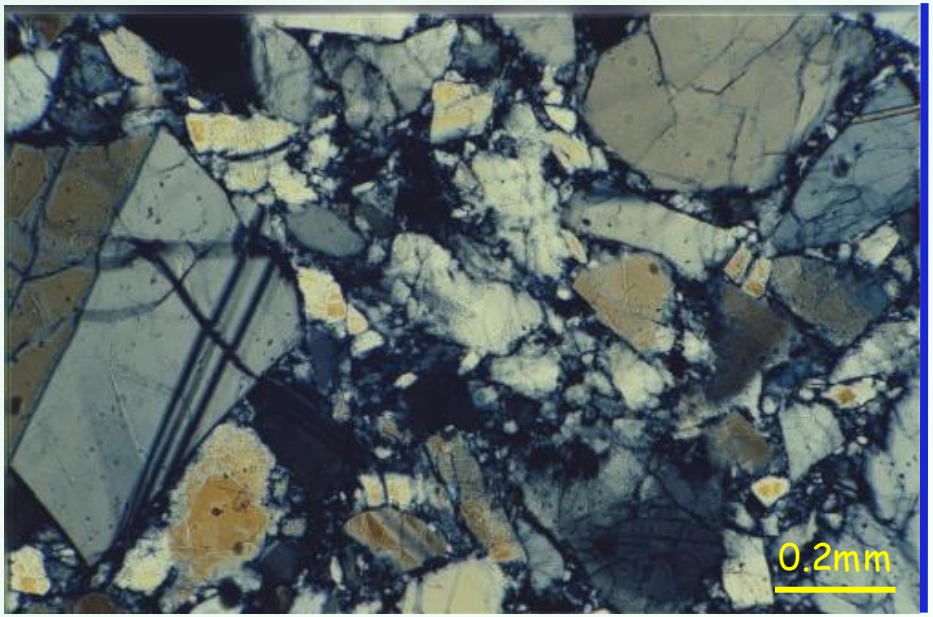
Lunar highlands across Mare Serenitatis

- Pale coloured mountains → significant mountains
- large boulder → impact breccia composed of angular fragments

Lunar anorthosite (lunar highlands)



Lunar anorthosite



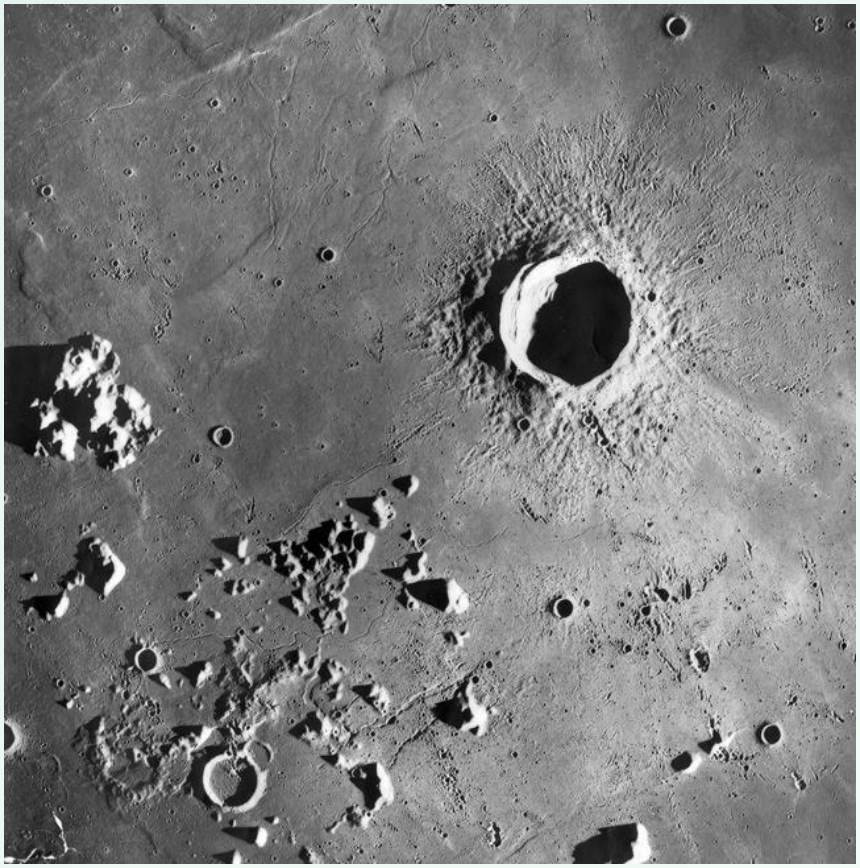
Lunar highlands anorthosite in thin section (X polars)

Lunar anorthosite v terrestrial anorthosite

- Anorthosites are plagioclase-rich rocks (90 – 100%) with a minor mafic content
- lunar anorthosites are light coloured whereas some terrestrial anorthosites are dark coloured
- lunar anorthosites are 90-100% Ca plagioclase end member
  c.f. terrestrial anorthosites 50 – 70% Ca end member
- terrestrial anorthosites are commonly very coarse-grained (>2cm)
  c.f. lunar anorthosites that are fine-grained

Lunar craters are undeformed

- Craters on the Moon are mostly perfectly circular
- no evidence of deformation for at least 4 billion years
- no evidence of any major large scale movements in Moon's crust



Lunar stratigraphy

- Lunar stratigraphy - same principles of stratigraphy can be applied to the Moon as on Earth

- prior to Apollo missions → Planetary Science division of the USGS examined the whole lunar surface → interpreted a basic geological stratigraphic sequence

- superposition of features enabled a relative Lunar Time Scale to be worked out

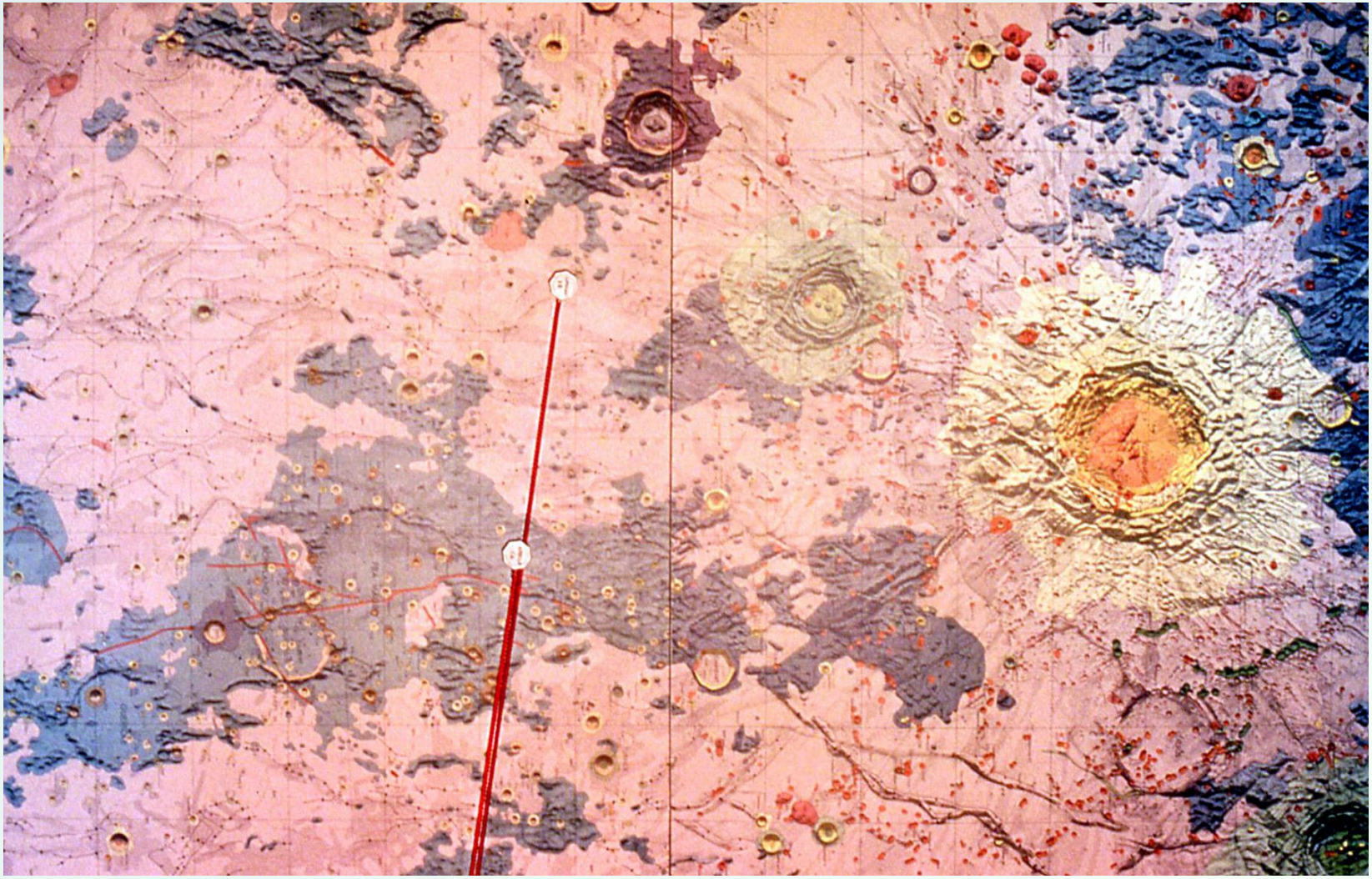
- geological maps of the lunar surface were prepared using this time scale

Relative dating of lunar landscape

- Highland terrains → heavily cratered → older
- maria occupy lowest parts of lunar surface (valleys, some craters)

  → low crater density → younger

Geological map interpreting the area around Copernicus (USGS)



Lunar stratigraphy

- Later radiometric dating has given absolute ages to this time scale
- most of the Moon's geological evolution was completed early

  - by about 3,000 Ma (contrast with the Earth)
- Earth and moon → different planetary evolutionary paths
- the Moon exhausted its internal energy supply early because it is

  a relatively small planetary body
- Youngest mare basalts → 3100Ma

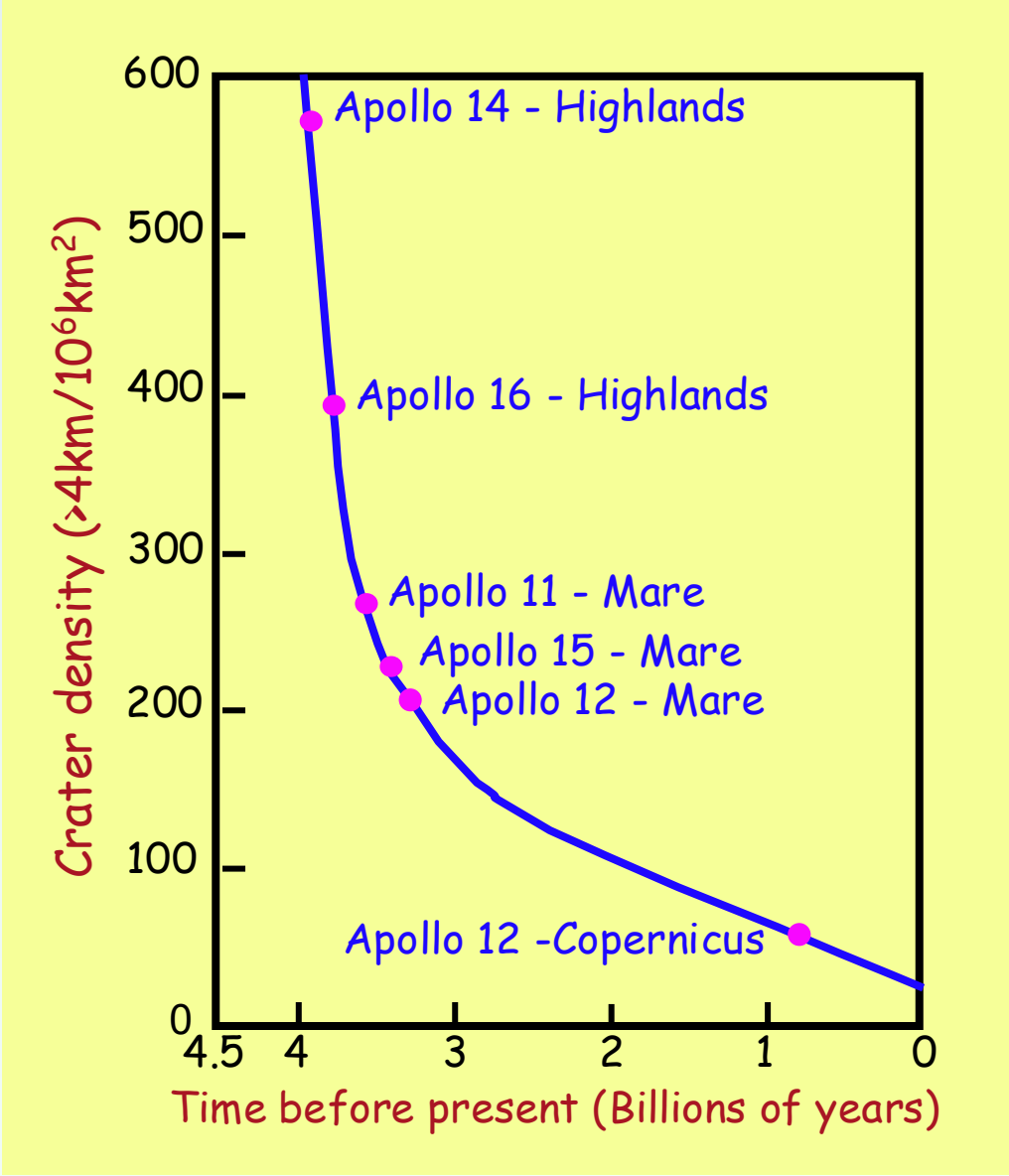
  Oldest mare basalts → 3900Ma
- the Moon preserves ancient stage of history of solar system

Lunar cratering history

- Lunar highlands → high density of overprinting craters with many older craters destroyed by younger ones
- this happened prior to formation of mare basalts
- highlands mostly complete in first 600Myr of Moon's history
- with progression of time, cratering has decreased to a small fraction of that 4Byr ago

Lunar cratering history

- ~4Ga rate of cratering began to plummet
- we can calculate number of impact craters that formed at different times in Moon's history
- high density crater overprinting has not happened since formation of younger mare basalts



Geological history of the Moon

4.6 - 4.0 Ga* Early intense impact cratering

4.2 - 4.0 Ga Large impacts → multi-ringed basins

4.0 - 3.9 Ga Sharp decrease in rate of cratering

3.9 - 3.1 Ga flooding of low lying areas → mare lavas

3.0 - 0 Ga continued light cratering

0.2 - 0 Ga formation of youngest bright ray craters

* 1Ga = 1 billion years = 1,000 million years

Evolution of Moon c.f Earth

- Relatively simple geological history for the Moon

- Two processes dominated:

  (1) impact cratering

  (2) volcanic activity

- these processes explain every feature observed on the Moon

- Earth processes more complex → more complex environments (e.g. rivers, lakes, oceans) produce a greater variety of rock types

- no sedimentary rocks on Moon → no agencies present to produce them